Security Analysis of Biometric Template Protection

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FP7 Integrated Project TURBINE (TrUsted Revocable Biometric IdeNtitiEs)

Background – TURBINE

- TURBINE project
  - TrUsted Revocable Biometric IdeNtitiEs
  - Privacy-enhanced solution for fingerprint biometrics
  - EU funded under FP7
  - http://www.turbine-project.eu
- Different protection methods developed by
  - Sagem Sécurité (France), Philips Research Europe (the Netherlands), Gjøvik University College (Norway)
- Evaluation tasks
  - Security testing: K.U.Leuven (Belgium – also legal evaluation)
  - Biometric performance testing: Gjøvik University College
- This talk reflects to some extent the security and privacy assessment of template protection techniques developed in TURBINE

Overview – Questions

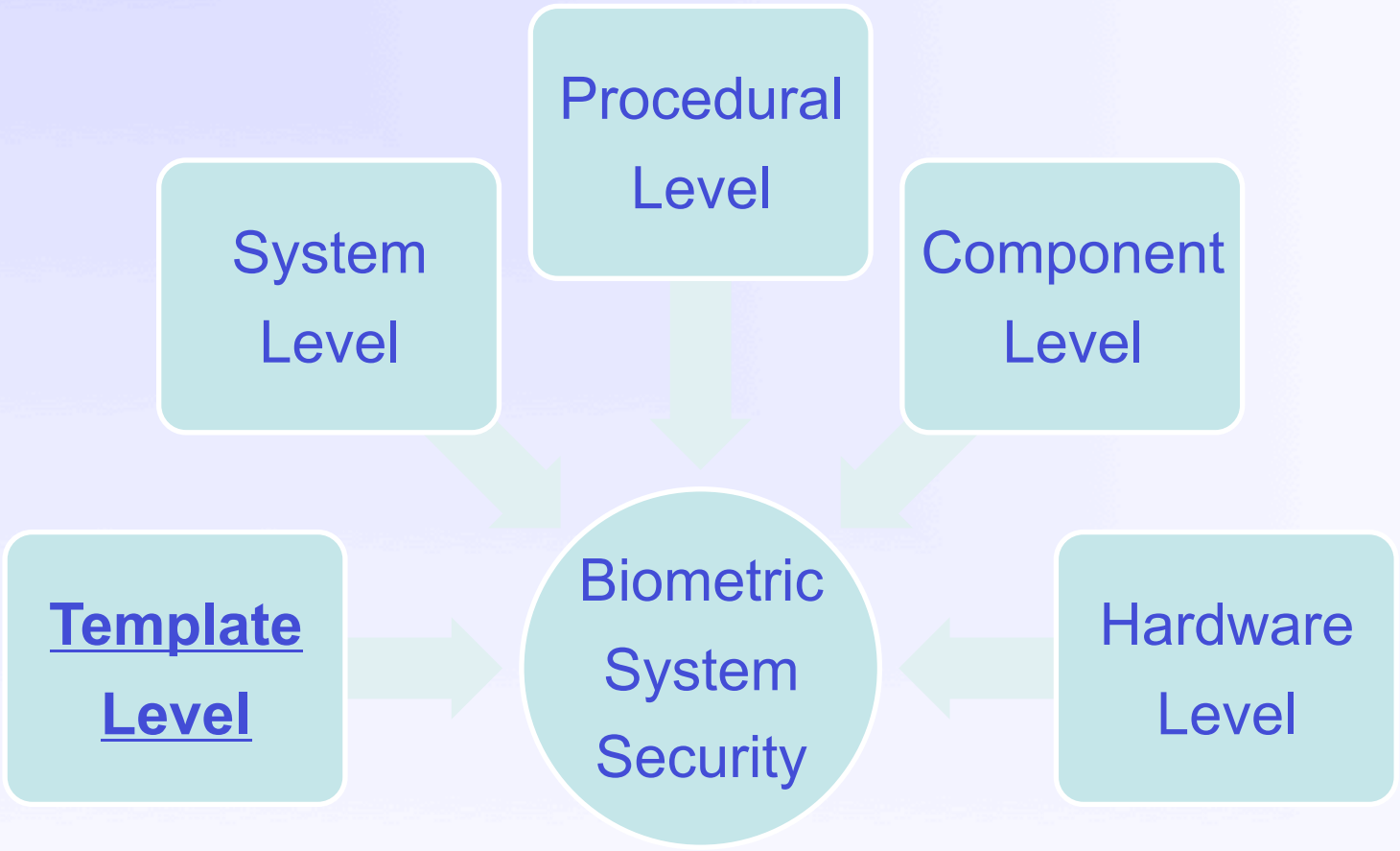
- What is biometric template protection?
- Why do we need it?
- What do we expect (requirements)?
- How can we achieve it (types)?
- **Which are the common pitfalls?**
- **Are their fundamental principles?**
- Where to start with the evaluation?
- How to compare results?
- What do we need more?

Overview

- The Meaning of Template Protection
- Why More Research on Template Protection is Needed
- Evaluation of Template Protection
- Objectives
  - Give intuition about fundamental principles
    - Design or analysis of new methods
  - Raise questions on how to evaluate
    - A common base for evaluation is needed

The Meaning of Template Protection

Biometric Template Protection at Multiple Levels



Template-Level Protection is Needed

- Many threats (impersonation, linking, etc.)
  - Conclusion: **do not store** reference data **in the clear**
- Current countermeasures
  - Encryption
  - Physical security
  - …

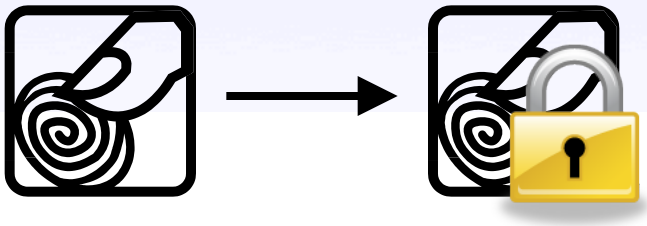
  => Complement with template-level protection
- Motivation from a risk management perspective (**what-if** analysis)
  - Physical protection may fail
  - Insider threats (trust assumptions no longer hold)
  - Desired **renewability** feature

Protection at Template Level

- **Biometrics-only** model: “cannot be lost/forgotten”
  - Assume no keys, passwords or smart cards for security
  - Possibly token as storage medium
  - Biometrics are **secrets**, but they are **noisy**
    - Classical data privacy schemes do not work
- Different methods have been proposed:
  - Quantization schemes
  - Discrete schemes
  - Mixed quantization/discrete schemes
  - Cancelable biometrics
  - …

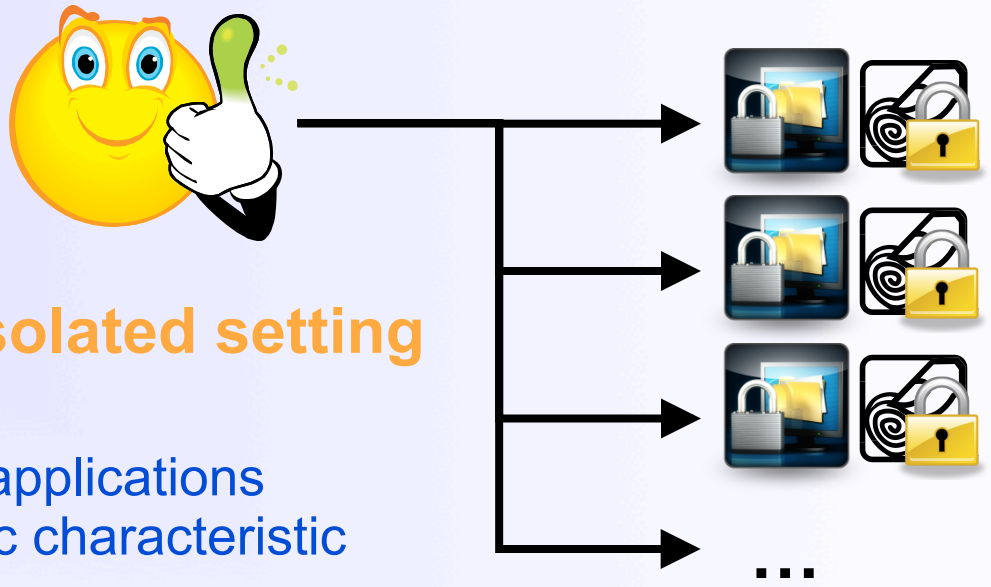
Template Protection in TURBINE

- Fuzzy schemes allowing noisy inputs
  - **Public data** helps to reliably extract bits
  - Hash extracted bits and store as reference
  - **Error-correction** to deal with noise
  - Implicit comparison: wrong result if distance > t
  - Classic example:
    - Fuzzy commitment (Juels & Wattenberg, CCS '99)
- TURBINE **pseudo identity** model
  - ISO 24745 Biometric Template Protection



Auxiliary Data (AD)
+
Pseudo ID
(secure reference)

Multi-Application Scenario



- Schemes **secure in isolated setting**
  - But reality…
  - Registered in multiple applications with the same biometric characteristic
- Multiple databases with protected templates
- We tend to forget
  - Different applications = different algorithms

Properties

- Main goals of template protection
  - One-way transformation: **irreversibility**
  - Diversification: **unlinkability** and revocability
  - Maintain biometric performance!
- Subtle issues
  - What does reversibility mean?
    - Reverse to enrolment sample or to other genuine/ impostor sample
  - Two-template irreversibility

Why More Research on Template Protection is Needed

"Fundamental" principles

A Word of Caution

- Personal ideas/opinion
- Not all principles are yet fundamental
  - Unproven, but give intuition
- Valid for all types of template protection?
- Recall
  - Template-level protection complements protection at other levels

User-Specific Side Information

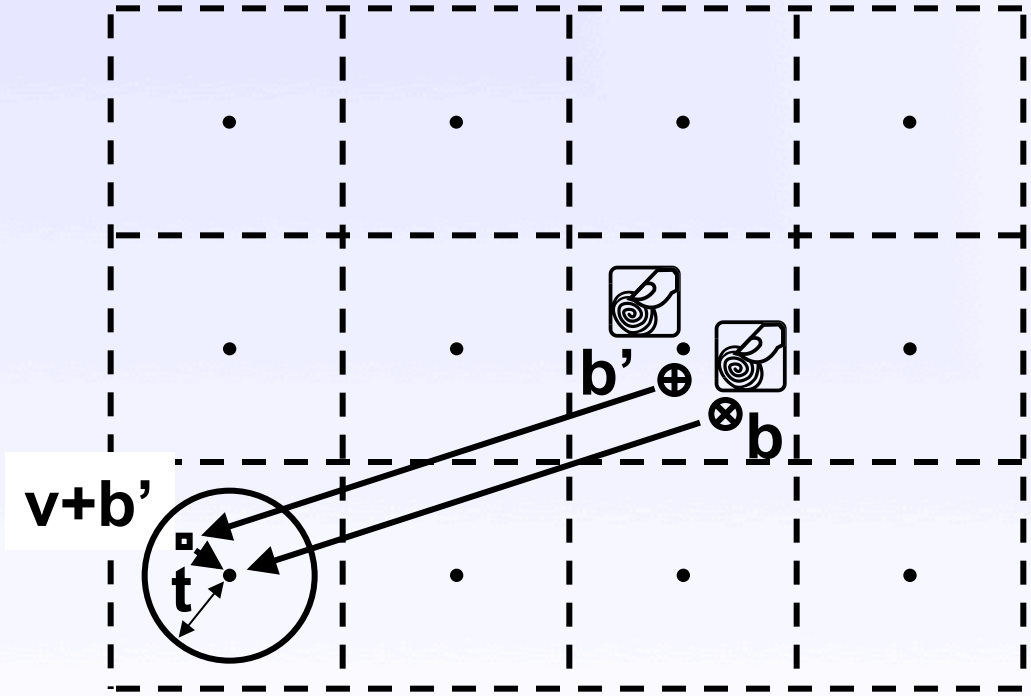
- Isometric **one-way** transformation
  - If b is a biometric sample and {b'} its neighbours
  - Take b somewhere else, thus {b'} also
  - This is why cryptographic hashing doesn't work
- There is no single transformation for all
  - Transformation is adjusted to enrolment sample
  - Side information **depends on input**
    - User-specific auxiliary data (public helper data)

Leakage Is Unavoidable

- What is leakage?
  - Information that reduces “uncertainty” about the enrolment sample
  - *It becomes “easier to guess”*
  - **Entropy reduction**
    - Fuzzy extractors (Dodis et al. EUROCRYPT 2004)
    - Adam Smith (Ph.D. Thesis 2004)
    - Only for discrete sources
- Where does it come from?
  - It is in the side-information
  - It is needed to **compensate noise**
  - Leakage is tolerated but should not be ignored

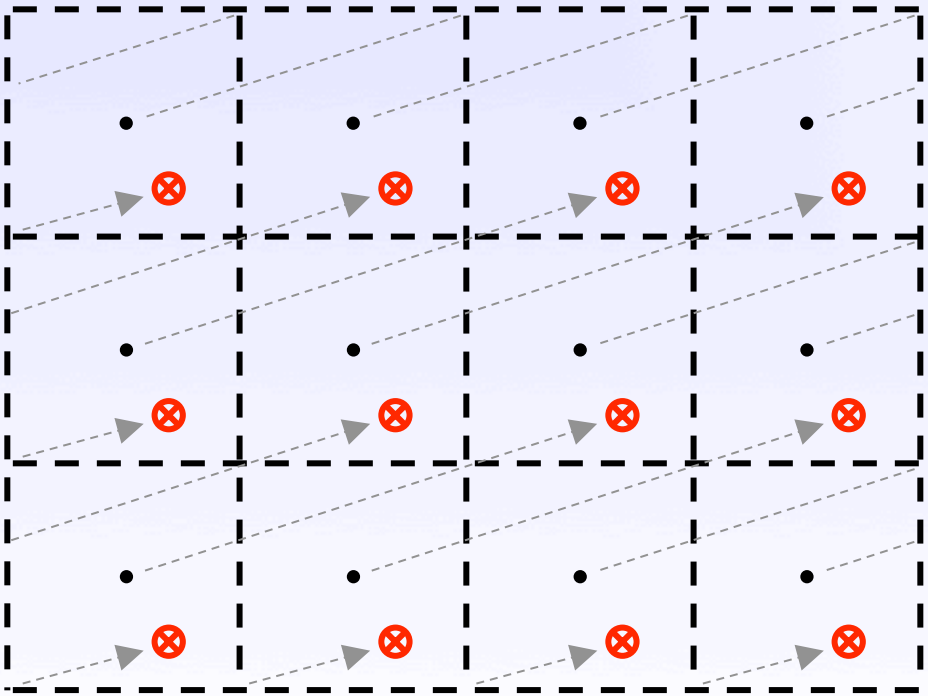
Leakage Is Unavoidable – Example

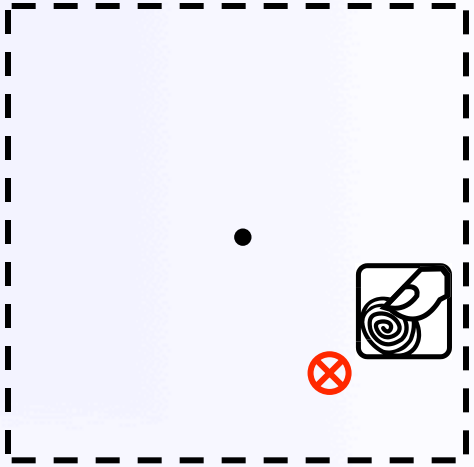
- Fuzzy commitment
  - Enrolment sample w, probe w'
  - Offset v (translation preserves distance)
  - Decode v + b' to c' and verify if h(c') = h(c)



Leakage Is Unavoidable – Example

- Theoretically proven **AD must leak** information
- Inverse code-offset from any codeword
- Uncertainty is reduced (no actual bits leaked)
- **Position in square is revealed** implicitly



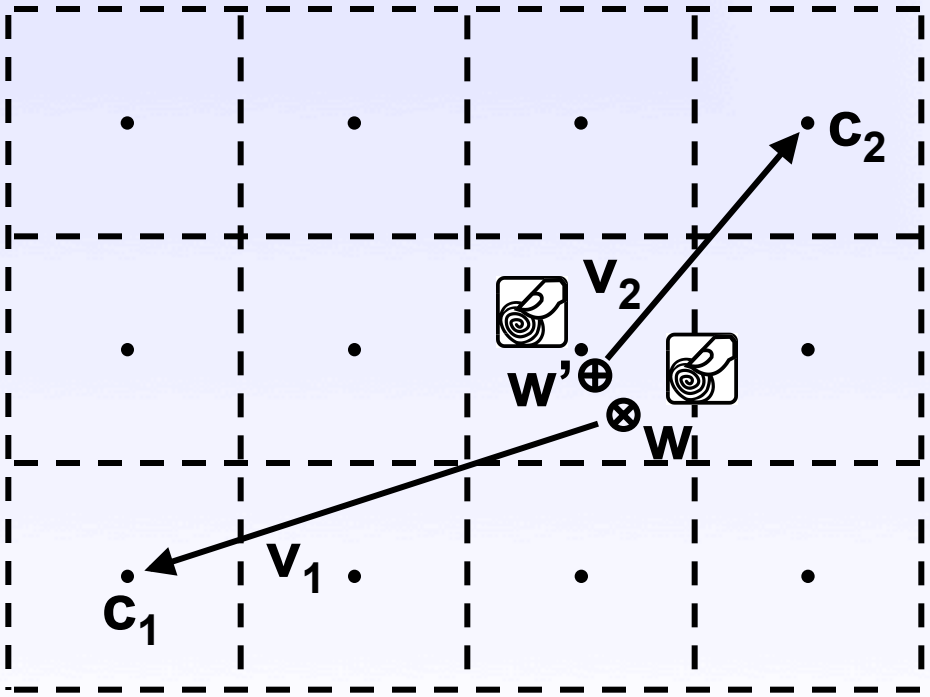


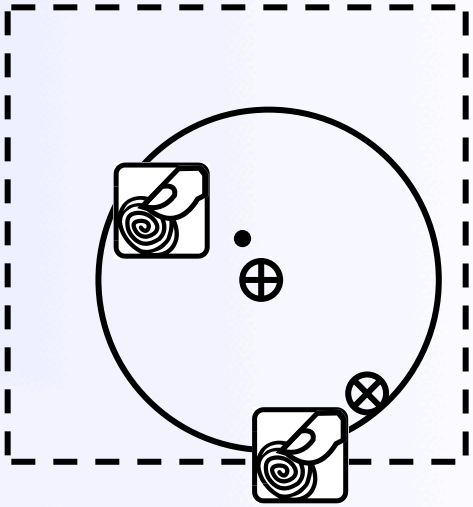
We Leak Too Much

- Current schemes leak to much
  - More leakage than needed to correct errors
  - This is why **cross-matching works** for fuzzy commitment and some quantization schemes
    - Simoens et al. S&P 2009
    - Buhan et al. SPEED 2009
- Can we improve?
  - Mathematical bounds (coding theory)

We Leak Too Much – Example

- Completely different PIs and ADs
- Cross-matching based on relative positions
- **Successful attack** against fuzzy commitment



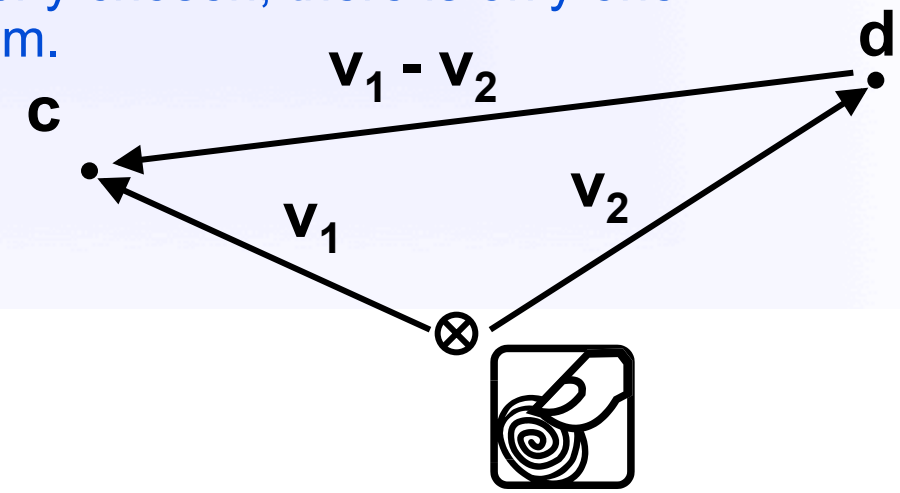


If You Leak, Leak Consistently

- Leakage is unavoidable
- **Leak the same** in different applications
  - This implies using the same algorithm
  - Impossible to maintain in practice?
- If not, **reverse two protected templates**
  - Theoretical attack (Simoens et al. S&P 2009)
  - Easy to see for discrete biometrics
    - Code-offsets, projection based
  - What about cancelable biometrics?

If You Leak, Leak Consistently

- Assume exactly same input is used
  - In practice enrolment samples are not equal
- Codewords c and d are from **different codes**
- Subtract offsets to obtain v = v1 − v2 = c − d
- Solve mathematical problem
  - Find c and d, from the first and the second code, who's difference equals v
  - If codes are not properly chosen, there is only one solution to this problem.



Linear = BAD

- Linear
  - "matrix", "offset", "translate", "rotate", "XOR"(!)
  - **Is not good** (cf. cryptography)
- Impact
  - Code-offsets
    - **Linkability** (cross-matching)
    - **Two-template reversibility**
  - Transformation of point-based features (e.g. minutiae sets)
    - **Correlation** between minutiae is preserved
- Non-linearity
  - Where to get it?
  - Conflicts with isometric input transformation

Other Observations

- **FAR attacks** are inherent to biometrics
  - Template-level protection requires additional measures
  - FAR attacks hurt more than you'd expect
    - Recover enrolment data from false accept
- Some schemes allow a **wider input range**
  - Examples: projection-based schemes, superimposing minutiae subsets
  - Attempt to counter some of the above attacks
  - Curiosity in Template Protection
    - Theoretical increase in false acceptance rate?
- Theory differs from practice
  - Evaluation requires working with real data
  - Distribution of binarized templates matters

Other Observations

- Including **hardware is out of scope** in the biometrics-only model
  - But it works! At least, we think so…
  - Nicer properties
- Information content (**entropy**) **is limited**
  - How many minutiae in a fingerprint?
  - What is the scanner resolution?
  - What is the range of the coordinates?
  - If you take into account noise tolerance?
- Is it not all discrete?
  - Quantization schemes
  - In the end… all the same?


TURBINE

Evaluation


SEVENTH FRAMEWORK
PROGRAMME


KATHOLIEKE UNIVERSITEIT
LEUVEN

Before You Start Evaluating

- Do you have a proper **framework**
  - To model/analyze ALL methods
    - E.g. fuzzy extractors for discrete biometrics
  - To set proper terms of reference
    - How to define and measure security properties?
- What is it that you want?
  - Application requirements
  - Are you willing to trade between properties
    - E.g. irreversibility vs. unlinkability
  - Are the requirements realistic and needed in practice?
- Get into the right mindset
  - Become a non-believer

During Evaluation

- Set clear adversary **objectives**
  - E.g. we want to compare/link protected templates
- **Test principles** mentioned above
  - Where is the leaked information?
  - In which form is it leaked?
  - How much is leaked and can we use it?
- How to **rank** different protection methods
  - Difficult without a unified framework
  - Already some consensus on security properties
  - Ongoing discussion in TURBINE and elsewhere

Expectations for The Future

- We need more **advanced techniques**
  - Non-linear methods
- We need more **formal approaches**
  - Unified security notions
  - Less “we think/believe…”
- We need **provable security**
  - Cf. public-key cryptography: security proven under some number-theoretic assumptions
- Are we ready for the first Template(-level) Protection Standard?

Thanks

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http://www.turbine-project.eu

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